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A Method Of Producing Slow Spin To Decrease The Dispersion Of Bazooka-Type Rockets (U)

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DEPARTMENT OF THE ARMY PROJECT No. 5B0305005
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0230

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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WESimon/mlu
Aberdeen Proving Ground, Md.
August 1955

A METHOD OF PRODUCING SLOW SPIN TO DECREASE THE DISPERSION OF BAZOOKA-TYPE ROCKETS (U)

ABSTRACT

Exhaust vanes installed on the M29A2 Practice Rocket, 3.5" produced 49% of the spin calculated using linear two-dimensional flat plate theory. Dispersion of the Practice Rocket, 3.5", M29A2 and the developmental Rocket, 3.5", T206, was substantially reduced by use of exhaust vanes producing 7 to 8 deg/ft initial spin.

INTRODUCTION

The angular dispersion of a non-spinning, fin-stabilized projectile characteristically increases with range[1]. Unavoidable manufacturing tolerances result in small asymmetries which produce a trim angle. The resultant lift force acts in a fixed direction if there is no spin. This trim lift force causes a departure from the intended trajectory which is basically a quadratic function of range[2]. If, however, the projectile is given a slow spin, the trim lift force rotates about the trajectory and a helical path results. The angular dispersion of the shell then becomes essentially independent of the range for flat fire.

The usual methods of inducing a slow spin for projectiles launched from a rifled tube are a partially effective rotating band and canted fins. Projectiles launched from a smooth bore tube must usually rely on only the second method. Unfortunately, the fins of some projectiles are relatively ineffective in producing spin. Previous tests (unpublished) on the Practice Rocket, 3.5", M29A2, established that fin cant of up to 10° did not produce measurable spin in the interval out to 1200 feet from the launcher.

However, in the case of a smooth-bore projectile propelled by a rocket motor, another method of inducing slow spin should be possible. Since the motion of large rockets, such as the V-2, is controlled (during burning) by deflecting the rocket exhaust with moveable vanes, it seems logical that slow spin in a small rocket could be induced by rather crude, small vanes in the exhaust stream.

The effect of this method of spin induction on dispersion should be particularly favorable for a bazooka-type rocket, whose rocket motor burns out before the projectile leaves the launcher. For a <u>free-burning</u> rocket, it is possible that jet asymmetry caused by the <u>installation of</u> vanes could counter-balance the favorable effect of averaging out the aerodynamic asymmetry.

The results of limited tests with jet vanes on the Practice Rocket, 3.5", M29A2 and the Rocket, 3.5", T206, which is still under development, are the subject of this report.

TEST PROCEDURE

One group of five Practice Rockets, 3.5", M29A2 (Fig. 1) was fired through yaw cards at 30, 40, and 60 feet from the launcher to establish the relation between exhaust vane angle setting and initial spin. The exhaust vane angle was set with a brass jig as shown in Figure 3. Spin was measured by means of a 1/2" stripe of machinist's layout fluid, painted axially on the ogive of each shell. This stripe produces a mark on the yaw card, establishing the orientation of the shell at that point. The shells were fired from a service launcher, M20A1B1, clamped to a 105mm howitzer carriage, (Figure 2).

A second group of five Practice Rockets with exhaust vanes set to produce 8 deg/ft initial spin was fired at a target at 1200 feet. Since the effect of asymmetry on dispersion is a function of range, the longest practical range was chosen[1].

A third group of five standard Practice Rockets without exhaust vanes was fired at a 1200 foot target for comparison with the second group.

At the same time that these tests were fired, a program investigating the causes of dispersion of the developmental Rocket, 3.5", T206 was being conducted in the Transonic Range(4). Phase 2 of this program consisted of fifteen rounds to be fired in the Transonic Range at a target at the end of the range (620 feet) from a control launcher which is a low-tolerance heavy steel pipe, rigidly mounted. Since the results of Practice Rocket firings were encouraging, five rounds of the T206 were made available for firing with exhaust vanes. The vanes were set to produce approximately 7 deg/ft initial spin, and the five rounds were fired under the same conditions as phase 2 of the original T206 program. Although detailed analysis of jump, yawing and swerving motion, and dispersion will properly be included in the report on the T206 program, preliminary results based only on target measurements are included here.

RESULTS

Calculations, Appendix 1, based on linear, two-dimensional, flat plate theory indicate that for the Practice Rocket, 3.5", M29A2, and the vanes used, it would be expected that:

Initial Spin (deg/ft) = 0.75 x Exhaust Vane Angle (deg)

The test results, as shown in Table 1 and Figure 7, indicate that:

Initial Spin (deg/ft) = 0.37 x Exhaust Vane Angle (deg)

or 49% of the theoretical value. Since the vane thickness is 12%, aspect ratio is 0.5, maximum angle of attack is 30°, and a boundary layer is present along the nozzle wall, the loss of 51% of the theoretical value is not surprising.

Examination of the exhaust vanes after firing indicated that the strength was adequate. Figure 4 shows Round No. 2, whose exhaust vanes were set at 30°, after firing. No deformation or major erosion by exhaust gases occurred, although flow lines are visible on the nozzle wall on each side of the vanes.

1 Unfortunately, the effect of variation in launching velocity on dispersion is also a function of range. 10 fps change in initial velocity of the M29A2 changes impact at 1200 feet by 9 feet vertically. Since previous tests(3) indicated a maximum variation in initial velocity of 40 to 50 fps for this round, only the horizontal probable error was considered to be significant.

Horizontal dispersion at 1200 feet for the Practice Rocket, 3.5", M29A2, with and without exhaust vanes, is presented in Table 2. Primarily because number of rounds is small, this reduction of probable error by the use of exhaust vanes could occur by chance once in twenty-two times[5].

Dispersion at 620 feet of the Rocket, 3.5" T206, is presented in Table 3. Figures 5 and 6 show the respective targets. This reduction in horizontal probable error by the use of exhaust vanes is quite significant, since this reduction could occur by chance only once in one hundred times[5]. Since the launching velocity of the T206 is much more consistent than that of the M29A2, vertical probable error, uncorrected for velocity dispersion, has been calculated in this case, and the reduction of vertical probable error by the use of exhaust vanes was approximately the same as that of the horizontal probable error.

CONCLUSIONS

The use of canted vanes in the exhaust of a fin-stabilized, bazooka-type rocket is a simple, effective method of producing slow spin. Spin calculated from linear, two-dimensional flat-plate theory is approximately twice the spin level observed in test firings. In a limited series of firings of the Practice Rocket, 3.5", M29A2 at 1200 feet, and the Rocket, 3.5" T206 at 620 feet, dispersion was substantially reduced by the use of exhaust vanes inducing 7 to 8 deg/ft initial spin.

Wayne E. Simon

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APPENDIX I

Practice Rocket, 3.5", M29A2, Physical and Ballistic Data

Axial Moment of inertia = 2.59×10^{-3} slug-ft^2

Nozzle Exit Area/Throat Area = 6.25

Propellent Burning Time at 70°F = .022 sec.

Average Launching Velocity at 70°F = 300 ft/sec

Average Chamber Pressure at 70°F = 5000 lbs/in^2

Assume: $\gamma = 1.25$ (for hot exhaust gases)

Exhaust Vane Data

Number = 3 at 120° spacing around exit of rocket nozzle

Dimensions = 0.25 inches wide (normal to flow) x 0.50 inches long x .06 inches thick

Material = SAE1010 cold-rolled steel, 16 gauge

Radial Distance to Center of Vane from Axis of Shell = 1.02 in.

Calculation of Force Required For One deg/ft Spin at Burnout

1 deg/ft = 1 x .01745 x 300 ft/sec = 5.24 radians/sec

$$\text{Acceleration} = \text{Spin/Burning Time} = \frac{5.24 \text{ radians/sec}}{.022 \text{ sec}} = 238 \text{ radians/sec}^2$$

Torque = Acceleration x Axial Moment of Inertia

$$= 238 \text{ radians/sec}^2 \times 2.59 \times 10^{-3} \text{ slug-ft}^2 = 0.616 \text{ lb-ft}$$

$$\text{Force} = \text{Torque/Radial Distance to Vane} = \frac{0.616 \text{ lb-ft} \times 12 \text{ in/ft}}{1.02 \text{ in}} = 7.25 \text{ lbs}$$

$$\text{Force per Vane} = \text{Force/Number of Vanes} = \frac{7.25}{3} = 2.42 \text{ lbs for one deg/ft spin}$$

Calculation of Lift Developed per Degree of Cant on Exhaust Vane

Exit Mach number = 3.05

From exit/throat area ratio of 6.25 and γ of 1.25, using graphs of

$$\text{formula:}\quad \frac{A}{A^*} = \frac{1}{M}\left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

where A = exit area

A^* = throat area

M = exit Mach number

Exit Total Pressure/Exit Static Pressure = 48

From exit Mach number of 3.05 and γ of 1.25, using graphs of formula:

$$\frac{P_T}{P} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

where P_T = Exit Total Pressure (lbs/in^2)

P = Exit Static Pressure (lbs/in^2)

Assume that Exit Total Pressure = Chamber Pressure (no loss in nozzle)

$$\text{Exit Static Pressure} = \frac{5000\ lbs/in^2}{48} = 103\ lbs/in^2$$

From linear, two-dimensional, flat-plate theory:

$$L = \frac{\gamma\ PM^2}{\sqrt{M^2 - 1}} \quad (2\ \ \alpha)\ (w\ \ell)$$

where L = Lift (lbs)

w = Width of plate (inches)

ℓ = Length of plate (inches)

α $\cancel{A}$ = Angle of attack (radians)

$$\text{Lift per Vane} = \frac{1.25 \times 103 \times (3.05)^2 \times 2 \times 0.25 \times .50 \times .01745}{\sqrt{(3.05)^2 - 1}}$$

$$= 1.81 \text{ lbs for one degree of cant}$$

Therefore: Spin at burnout (deg/ft) $= \frac{1.81}{2.42}$ x Exhaust Vane Cant (deg)

$= 0.75$ x Exhaust Vane Cant (deg)

TABLE I

No.	Round	Exhaust Vane angle (deg.)	Spin (deg/ft)
1	3470	2	0.9
2	3473	30	11.7
3	3474	20	7.1
4	3472	8	3.0
5	3471	10	3.5

NOTE: Spin measured in interval from 30 to 60 feet from launcher.

TABLE II

HORIZONTAL DISPERSION AT 1200 FEET
3.5" ROCKET M29A2

a) Five Rounds With Exhaust Vanes (22°), Burn out Spin = 8 deg/ft

Round	mils from Center of Impact
3475	+ .54
3476	- .45
3477	- .10
3478	+ .67
3479	- .70

Probable error = 0.40 mils

b) Five Rounds, Standard, Burn out SPIN = 0

Round	mils from Center of Impact
3480	- .57
3481	-1.47
3482	-1.30
3483	+1.51
3484	+1.85

Probable error = 1.06 mils

TABLE III

DISPERSION AT 620 FEET
3.5" ROCKET T206

a) Five Rounds With Exhaust Vanes at 20°, ~~Initial~~ BURN OUT Spin = 7 deg/ft

Round	Horizontal (Mils)	Vertical (Mils)
3525	+ .26	- .60
3526	+ .20	+ .03
3527	- .57	+ .39
3528	+ .43	+ .57
3529	- .33	- .40

Probable error, mils, H = 0.29, V = 0.34

TABLE III (continued)

Burn out.

b) Fifteen Standard Rounds, [redacted] Spin = 0

Round	Horizontal (Mils)	Vertical (Mils)
3510	+ 1.67	+ 1.16
3511	+ .09	- .67
3512	+ .46	- 2.37
3513	- 3.30	+ .16
3514	+ .55	- .57
3515	- .71	+ 1.08
3516	+ 2.11	- .65
3517	+ .73	+ .56
3518	- 1.72	+ 1.58
3519	+ 2.38	- 1.00
3520	+ .31	+ 2.91
3521	+ .50	- 1.36
3522	- 2.18	- 1.09
3523	- .95	+ 1.29
3524	+ .03	- 1.02

Probable error, mils, H = 1.06, V = .94

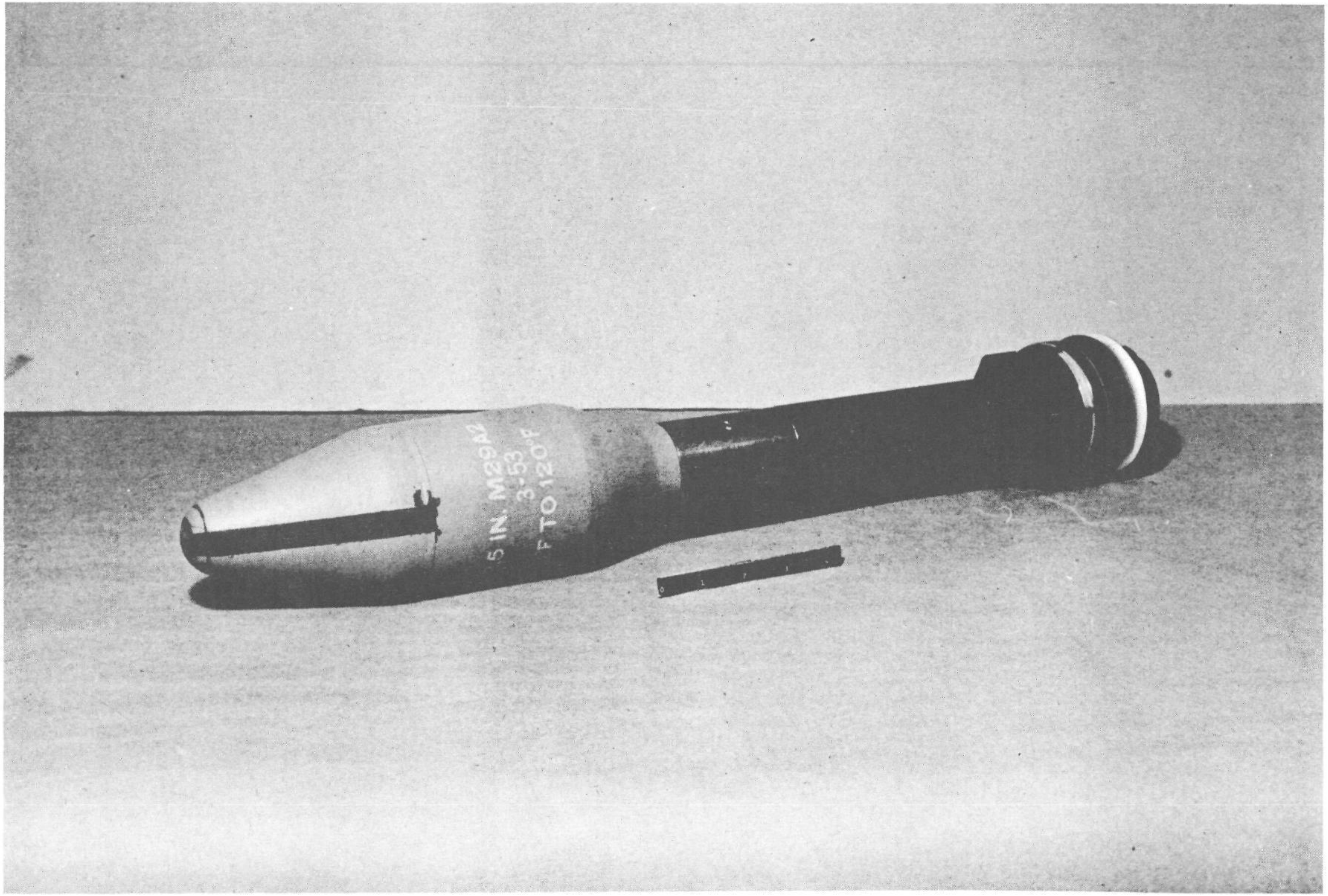

Figure 1. Practice Rocket, 3. 5", M29A2 with Stripe of Machinist's Blue.

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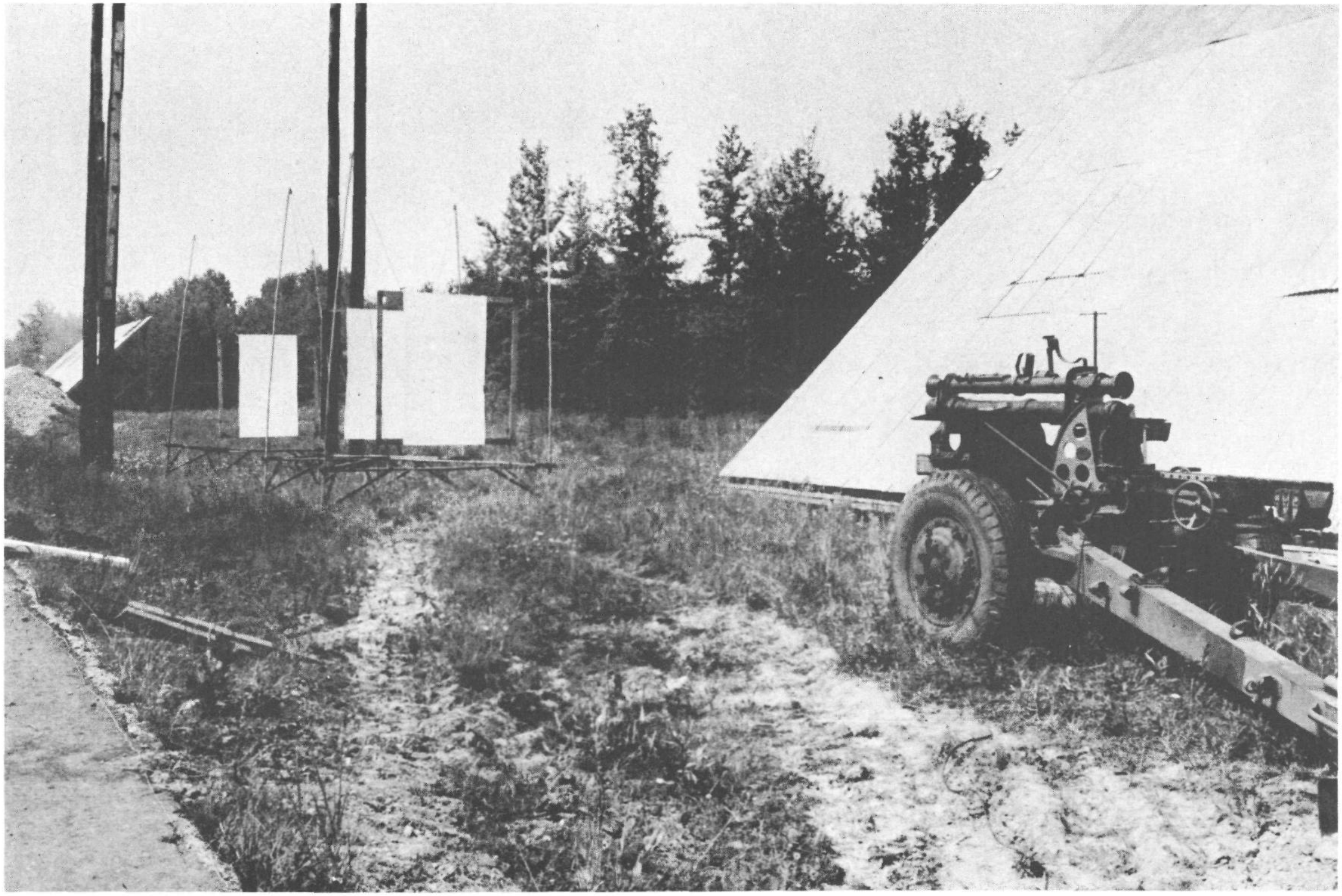

Figure 2. Service Launcher, M20A1B1, Clamped to 105mm Howitzer Carriage.

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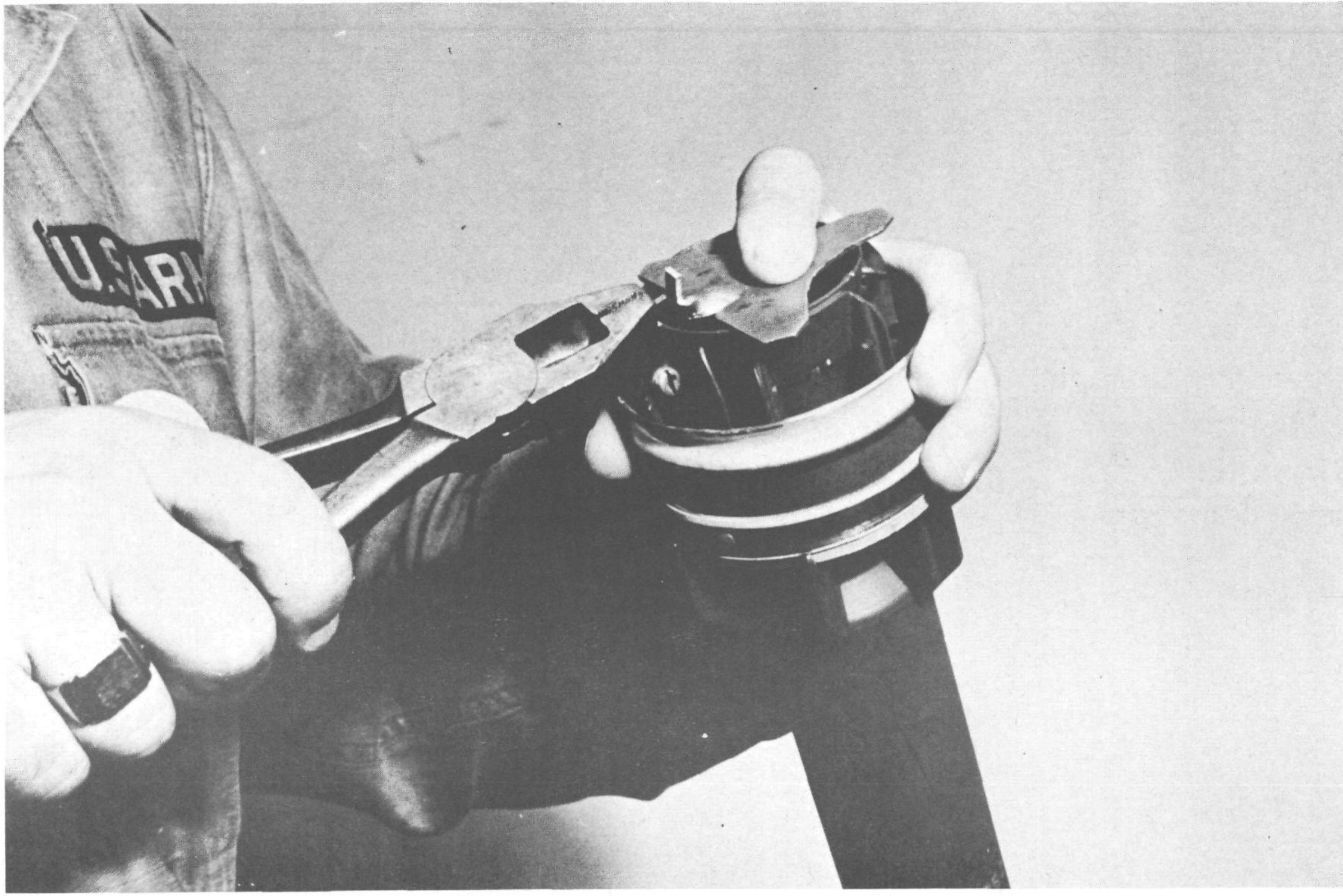

Figure 3. Bending Exhaust Vane to Angle Set on Jig.

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Figure 4. Recovered Projectile Showing 30° Exhaust Vanes after Firing.

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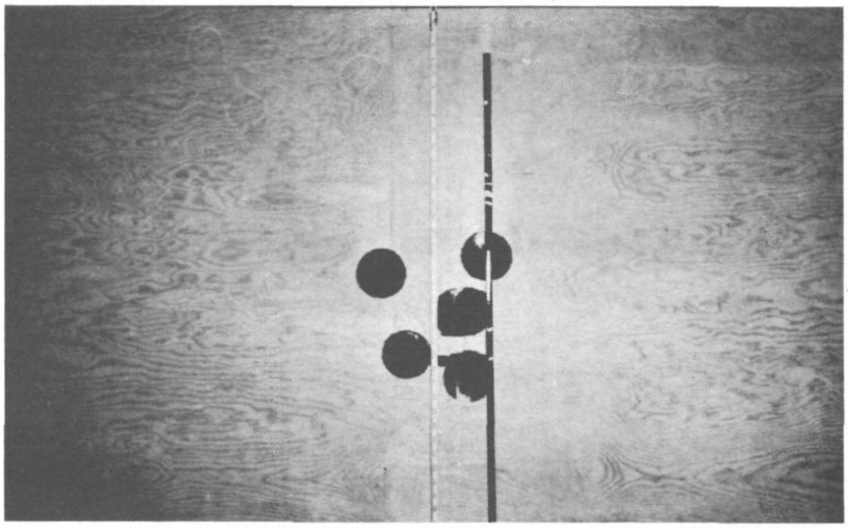

Figure 5. With Exhaust Vanes Set at 20°.

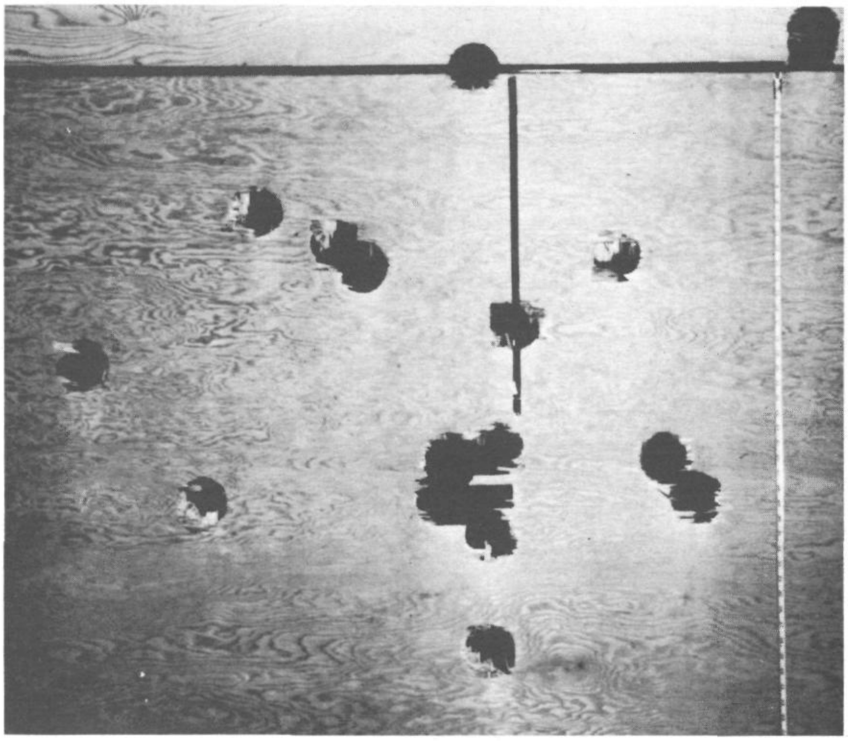

Figure 6. Without Exhaust Vanes
Rocket, 3. 5", T206,
Targets at 620 ft.

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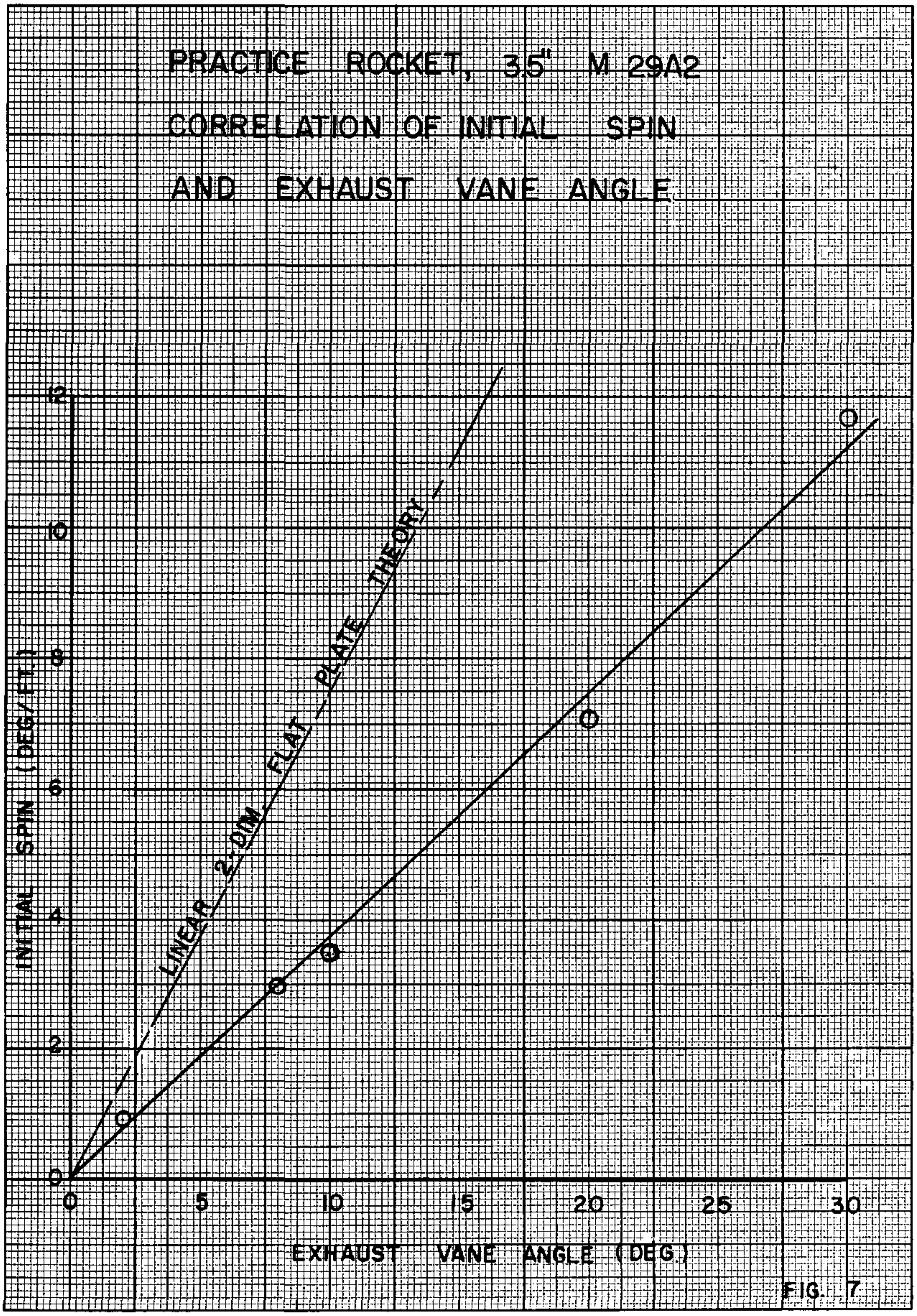

FIG. 7

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